

## Scrolling color projection display using surface plasmon tunable filters

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Surface plasmon tunable filter (SPTF) is a new technology under development at Jet Propulsion Lab. When applying to LCD projectors, SPTF can simplify the system structure, and enhance the efficiency. A scrolling SPTF which consists three SPTFs can generate scrolling red, green and blue colors, is able to enhance the efficiency of a single panel LCD projector up to the same level as a three panel LCD projector. A scrolling S1'TF which consists six SPTFs and can generate two set of scrolling RGB colors, will enable a single panel LCD projector to be 100% more efficiency than the current three panel LCD projector.

Keywords: surface plasmon, electro-optics, display, projector, LCD

Efficiency, brightness and cost are big concerns of projection displays. Generally speaking, a single panel projector is cheaper, but has low efficiency and low brightness.

The surface plasmon has been studied since the 1960's. It can be described as a collective oscillation in electron density at the interface of a metal and a dielectric. At surface plasmon resonance, the reflected light vanishes. This resonance is referred to as attenuated total reflection, and is dependent upon the dielectric constant of both the metal and the dielectric. If an electro-optical (EO) material is used as the dielectric and a voltage is applied to change the surface plasmon resonance condition, the reflected light can be modulated<sup>1</sup>. A surface plasmon laser light modulator with a contrast ratio greater than 100:1 has been reported<sup>2</sup>.

If we consider the surface plasmon light modulator in the frequency space, the photons at surface plasmon resonance will be absorbed and the photons out of the resonance will be totally reflected. If a voltage is applied on the EO material, the index of refraction of the EO material will change, the surface plasmon resonance frequency will change, therefore the reflection spectrum can be controlled by the applied voltage, and an electronically tunable notch color filter is formed<sup>3</sup>. Experiment has shown when a 30-v voltage is applied on a surface plasmon tunable notch color filter, the resonance frequency can be shifted from red (640 nm) to blue (450 nm).

In 1996, the S1' tunable bandpass filter using coupled S1' waves was invented at JPL<sup>4,5</sup>. The structure of this SP tunable bandpass filter is shown in Fig. 1. A symmetric geometry of metal/ITO/metal is employed. Two high index glass prisms are used for the coupling. A thin metal film is evaporated on each prism respectively. A thin EO material

layer is sandwiched by the two prisms. The EO layer is less than one wavelength thick. When a S<sub>1</sub>' wave is excited on one side of metal/EO material interface by the incident photons, the energy of resonance photons will be converted into the motion of free electrons of the metal film. And the optical field will penetrate the thin EO layer and excite another S<sub>1</sub>' wave with the same frequency at the other metal interface because of the symmetric structure. The resonance photons then will be re-radiated out as the transmitted light. When a voltage is added on the EO material, the index of the EO material will change, the S<sub>1</sub>' resonance frequency will change, and the transmission spectrum will change.

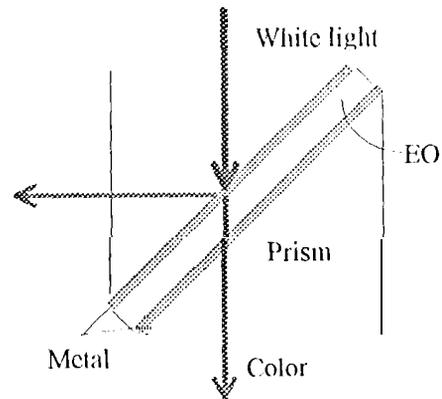


Fig.1 Structure of surface plasmon tunable filter (SPTF).

Fig. 2 shows the theoretical calculation of transmission spectrum for two silver film separated by a 150 nm EO material layer. Without voltage, the index change  $dn$  is zero, and the peak transmission is at 450 nm (blue). When the voltage induced index change of the EO layer has an increase of a  $dn=0.2$ , the transmission peak shifts to 530 nm (green), When the index change of  $dn=0.5$ , the peak transmission shifts to 650 nm (red).

The intensity of peak transmission depends on the optical properties and the thickness of the metal. Metals with small imaginary part of the dielectric constant will have higher peak transmission and narrower bandwidth. On the other hand, a thinner metal layer will give greater peak transmission and broader bandwidth.

The shape of the transmission also depends on the coupling geometry of surface plasmon waves, if a five layer system, which consists three metal

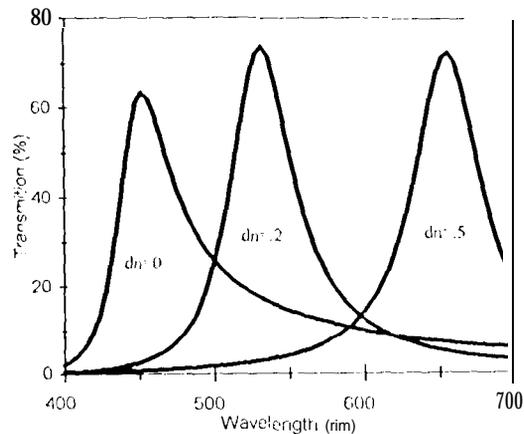


Fig 2 Transmission spectrum of SPTF. When the EO material has an index change of 0.5, the transmission shifts from blue to red.

layers and two EO material layer is used, then there will be four surface plasmon waves coupled to each other, and the transmission spectrum will look more like a rectangular shape with peak transmission over 70%.

Since surface plasmon is a surface effect, only a very thin liquid crystal layer is responsible to surface plasmon excitation. It has been reported that the switching time of surface plasmon in liquid crystal is two orders of magnitude faster than the switching time of bulk liquid crystal. For the surface plasmon tunable notch filter, a switching time of 0.2 ms has been observed, For surface plasmon tunable bandpass filter, the switching time should be even faster because of the very thin liquid crystal layers.

Being a fast switching device, and able to generate field sequential red, green and blue colors, surface plasmon tunable filter can be used for both projection and direct view display devices<sup>6,7,8</sup>. For a single panel projection display, the surface plasmon tunable filter can be used to replace the color wheel to generate the field sequential red, green and blue colors to shine on either a liquid crystal display panel or a digital micro-mirror device to generate a color image.

The concept of using SPTF to generate scrolling colors for projection displays is shown in Fig. 3, the device consists three SPTFs and two internal reflection prisms. Light from each SPTF will be projected onto 1/3 section of the LCD panel. At the first 1/180 of second, the top SPTF only allow the red color passes through, green and blue colors are reflected by the top SPTF and redirected by a prism to the middle SPTF; the middle SPTF only allows green color to pass through and reflects the blue color; finally the blue color is reflected by another prism and pass through the third SPTF as shown in Fig. 3-a. Now the top 1/3 of the LCD panel passes red, the middle 1/3 of the LCD panel passes green and the bottom 1/3 of the LCD panel passes blue. Then on the screen, the top 1/3 of screen shows a red image, the

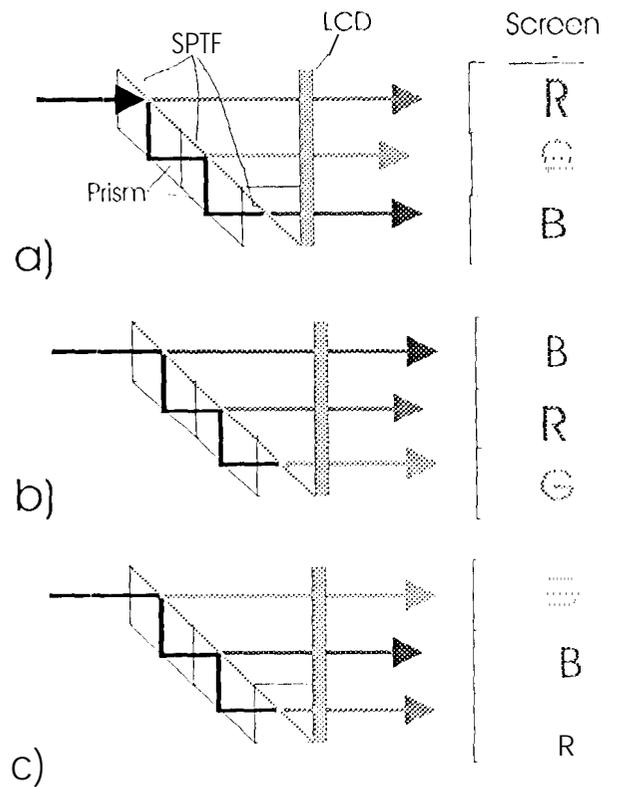


Fig.3 Surface plasmon tunable filter (SPTF) can generate scrolling colors for projection displays

middle 1/3 of the screen shows a green image and the bottom 1/3 shows a blue image.

At the second 1/180 second, by applying voltage, the pass band of the top SPTF shifts to blue, the pass band of the middle SPTF shifts to red, and the pass band of the

bottom SPTF shifts to green; then on the screen, the colors scrolled down, red color goes down to the middle, green color goes down to the bottom, and blue color goes up to the top; as shown in 3-b.

At the third 1/180 second, by applying voltage, the pass band of the top SPTF shifts to green, the pass band of the middle SPTF shifts to blue, and the pass band of the bottom SPTF shifts to red; then on the screen, the colors scrolled down again, blue color goes down to the middle, red color goes down to the bottom, and green color goes up to the top; as shown in 3-c.

During each third period, which lasts 1/180 second, the voltage applied to each SPTF could be changed so as to change its pass wavelength band to that of a different primary color. The temporal sequence of voltages applied to the three SPTFs could be chosen to make the colors on the corresponding three subdivisions of the display area scroll downward or upward. This scrolling SPTF which consists three SPTFs can generate scrolling red, green and blue colors, is able to enhance the efficiency of a single panel LCD projector up to the same level as a three panel LCD projector.

Because SPTF only allow one color of the p-polarized light pass through and reflects all of the s-polarized light. A second set of SPTFs, which consists three SPTFs and is in a position perpendicular to the first set of SPTFs, can be used to modulate the s-polarized light. Therefore, a scrolling SPTF which consists six SPTFs and can generate two set of scrolling RGB colors, will enable a single panel LCD projector to be 100% more efficiency than the current three panel LCD projector.

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